Catchment Risk Assessment of Steroid Oestrogens for Sewage Treatment Works

Andrew Johnson, Richard Williams, Virginie Keller and Andy Young
The requirement

To predict where in the English and Welsh river network endocrine disruption risk is greatest

Help identify the sewage treatment works most responsible
Short summary

- LF2000-WQX has been adapted to enable it to model oestrogens and endocrine disruption risk in English and Welsh catchments.
- To this end, information on the location, dry weather flow, human PE and treatment type of every STP was collected from the EA and Water Companies – thank you!
- With this data, predictions for three individual steroid oestrogens were made in each of 357 catchments, 2,137 STPs and 10,313 river reaches.
In general terms the concentrations of oestrogens in rivers will be a reflection of population density versus available dilution.
Water available to dilute an individual’s daily waste – a regional comparison

m³/d/capita
So before we get into detailed modelling, from the general regional population vs hydrology profile, we would expect high exposure to oestrogens in areas like the Midlands, but not in Wales!
Methodology

Model predicts oestrogen excreted per capita

Oestrogen removal predicted in STW from literature (majority)
Lower E1 removal rate assumed in Biological Filters (SB)

Final effluent value dependent on STW DWF

Receiving water concentrations calculated from dilution (hydrological model) and biodegradation rate (literature and mean water temperature)
Transformation of E2 into E1 calculated in the model

Predicted concentrations of E1, E2, and EE2 converted to one of three endocrine disruption risk levels
## Risk Classes in E2 Equivalents

<table>
<thead>
<tr>
<th>Risk Class</th>
<th>E2 Equivalent (ng/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Risk</td>
<td>&lt;1</td>
</tr>
<tr>
<td>At Risk</td>
<td>&gt; 1 and &lt;10</td>
</tr>
<tr>
<td>High Risk</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>
Contribution of individual steroid oestrogens to overall oestrogenic potency in effluent

Activated Sludge

EE2 41%
E1 44%
E2 15%

Biological Filters

EE2 26%
E2 10%
E1 64%
Results are expressed as mean concentrations, how does this work?

- The model estimates the probability distribution of concentrations of each steroid in each river reach.
- This distribution comes from combining other distributions that describe both the flow and chemistry of upstream flows and discharges.
- Calculated within a Monte Carlo framework.
- These results are given as a mean concentration (90\textsuperscript{th} percentile values are also given in the report).
Monte Carlo approach to predict downstream oestrone concentrations and assign a probability distribution

\[ E_{1d} = Q_{up}E_{1up} + Q_{e}E_{1e} \]

Sample from Distributions and do this mass balance calculation many times (shots)
This risk assessment has been based on readily available data sets and due diligence has been taken in quality controlling these data. However, there are limitations:

- The use of consented STW dry weather flows rather than measured values
- The use of a universal removal efficiency in STPs (save for biological filters)
- The selected PNEC used (which might change the class boundaries and the calculation of E2 equivalent concentrations).
- Was the association between the STP and receiving water course correct?
- Model so far only tested against effluents, accuracy at catchment scale still untested!

The risk assessment could be refined in accordance with:

- Developments in the scientific understanding of oestrogen effects on the species of concern,
- New information on treatment efficiencies
- When the specific objective is to devise a strategy for environmental improvement, or risk reduction, at the local scale.
Detailed regional Assessments
Predicted Risk Categories

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number Reaches Mean</th>
<th>Number Reaches 90th</th>
<th>Length (km) Mean</th>
<th>Length (km) 90th</th>
<th>% Total Length Mean</th>
<th>% Total Length 90th</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Risk</td>
<td>1,163</td>
<td>834</td>
<td>2,434</td>
<td>1,534</td>
<td>48</td>
<td>30</td>
</tr>
<tr>
<td>At Risk</td>
<td>1,007</td>
<td>1,177</td>
<td>2,571</td>
<td>3,183</td>
<td>50</td>
<td>63</td>
</tr>
<tr>
<td>High Risk</td>
<td>70</td>
<td>229</td>
<td>89</td>
<td>377</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>
Southern Risk Assessment Map

Discharge Predicted
- SAS Risk Categories
- SB
- TA1
- TA2
- TB1
- TB2

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number reaches</th>
<th>Length (km)</th>
<th>% Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean 90th</td>
<td>Mean 90th</td>
<td>Mean 90th</td>
</tr>
<tr>
<td>No Risk</td>
<td>882 728</td>
<td>981 793</td>
<td>65 53</td>
</tr>
<tr>
<td>At Risk</td>
<td>353 444</td>
<td>508 652</td>
<td>34 43</td>
</tr>
<tr>
<td>High Risk</td>
<td>21 84</td>
<td>10 54</td>
<td>1 4</td>
</tr>
</tbody>
</table>
Thames Risk Assessment Map

Predicted Risk Categories

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number Reaches Mean</th>
<th>Number Reaches 90th</th>
<th>Length (km) Mean</th>
<th>Length (km) 90th</th>
<th>% Total Length Mean</th>
<th>% Total Length 90th</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Risk</td>
<td>382</td>
<td>335</td>
<td>309</td>
<td>311</td>
<td>30</td>
<td>19</td>
</tr>
<tr>
<td>At Risk</td>
<td>328</td>
<td>300</td>
<td>1,107</td>
<td>1,127</td>
<td>67</td>
<td>68</td>
</tr>
<tr>
<td>High Risk</td>
<td>52</td>
<td>127</td>
<td>44</td>
<td>222</td>
<td>3</td>
<td>13</td>
</tr>
</tbody>
</table>
**Wales Risk Assessment Map**

### Predicted Risk Categories

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number Reaches</th>
<th>Length (km)</th>
<th>% Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>90th</td>
<td>Mean</td>
</tr>
<tr>
<td>No Risk</td>
<td>1447</td>
<td>1323</td>
<td>2,597</td>
</tr>
<tr>
<td>At Risk</td>
<td>105</td>
<td>225</td>
<td>133</td>
</tr>
<tr>
<td>High Risk</td>
<td>3</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

- **Discharges**: P, SAS, SB, TA1, TA2, TB1, TB2
- **Risk Categories**: No risk, At risk, High risk

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**Discharges List**:
- P
- SAS
- SB
- TA1
- TA2
- TB1
- TB2
### Midlands Risk Assessment Map

#### Predicted Risk Categories

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number Reaches</th>
<th>Length (km)</th>
<th>% Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>90th</td>
<td>Mean</td>
</tr>
<tr>
<td>No Risk</td>
<td>453</td>
<td>352</td>
<td>1,329</td>
</tr>
<tr>
<td>At Risk</td>
<td>537</td>
<td>501</td>
<td>1,691</td>
</tr>
<tr>
<td>High Risk</td>
<td>52</td>
<td>189</td>
<td>50</td>
</tr>
</tbody>
</table>

- **Discharges**: SAS, SB, TA1, TA2, TB1, TB2
- **Risk Categories**: No risk, At risk, High risk
North East Risk Assessment Map

Predicted Risk Categories

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number Reaches</th>
<th>Length (km)</th>
<th>% Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>90th</td>
<td>Mean</td>
</tr>
<tr>
<td>No Risk</td>
<td>604</td>
<td>462</td>
<td>1,646</td>
</tr>
<tr>
<td>At Risk</td>
<td>437</td>
<td>496</td>
<td>1,004</td>
</tr>
<tr>
<td>High Risk</td>
<td>31</td>
<td>114</td>
<td>33</td>
</tr>
</tbody>
</table>
North West Risk Assessment Map

Predicted Risk Categories

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number Reaches</th>
<th>Length (km)</th>
<th>% Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>90th</td>
<td>Mean</td>
</tr>
<tr>
<td>No Risk</td>
<td>593</td>
<td>540</td>
<td>1,169</td>
</tr>
<tr>
<td>At Risk</td>
<td>226</td>
<td>238</td>
<td>601</td>
</tr>
<tr>
<td>High Risk</td>
<td>19</td>
<td>60</td>
<td>16</td>
</tr>
</tbody>
</table>
### South West Risk Assessment Map

**Discharges**
- SAS
- SB
- TA1
- TA2
- TB1
- TB2
- SA

**Predicted Risk Categories**
- No risk
- At risk
- High risk

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Number Reaches</th>
<th>Length (km)</th>
<th>% Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Mean</strong></td>
<td><strong>90th</strong></td>
<td><strong>Mean</strong></td>
</tr>
<tr>
<td>No Risk</td>
<td>1216</td>
<td>998</td>
<td>2,462</td>
</tr>
<tr>
<td>At Risk</td>
<td>316</td>
<td>489</td>
<td>461</td>
</tr>
<tr>
<td>High Risk</td>
<td>16</td>
<td>61</td>
<td>6</td>
</tr>
</tbody>
</table>
Key scientific findings

- Majority of reaches in England and Wales are predicted to be not at risk of endocrine disruption (61%)
- Significant minority predicted to fall within the at risk category (39%)
- Only around 1% of reaches fall into the high risk endocrine disruption category
- All regions contain some locations at risk, but Thames, Midlands and Anglian most affected
How the model might be used

• Enables the regulator to rapidly identify the river reaches most at risk from endocrine disruption

• Assists the regulator to identify the STW that make the greatest (negative) contribution to the most at risk river reaches
Changing the model output can help highlight the uppermost group of reaches at risk and focus on the responsible STWs
Predicted E2 equiv concentrations divided here into five classes

**Discharges**
- SAS
- SB
- TA1
- TA2
- TB1
- TB2

**Predicted E2 equiv (ng/l)**
- 0.0 - 1.0
- 1.0 - 2.5
- 2.5 - 5.0
- 5.0 - 10.0
- > 10.0
Confidence in the model predictions?

- Helpful to compare these risk predictions with previous EA surveys of the incidence and severity of intersex in wild roach (desk study).
- Also would be helpful to compare the PECs generated by the model against measured oestrogen concentrations throughout some selected river catchments (i.e. field monitoring study testing not only the models ability to predict effluent concentrations, but also in-stream concentrations as influenced by dilution and attenuation).
Key uncertainties?

• Have we got our understanding of deconjugation of EE2 within sewage treatment correct? Important because it is such a potent endocrine disrupter.

• Removal rates in different types of STP, have we got them right?

• Is the England and Wales wide equation to convert of flow to velocity (in-river residence time) acceptable everywhere? Greater residence times mean more in-stream degradation, could be important in slow flowing regions like Anglian?